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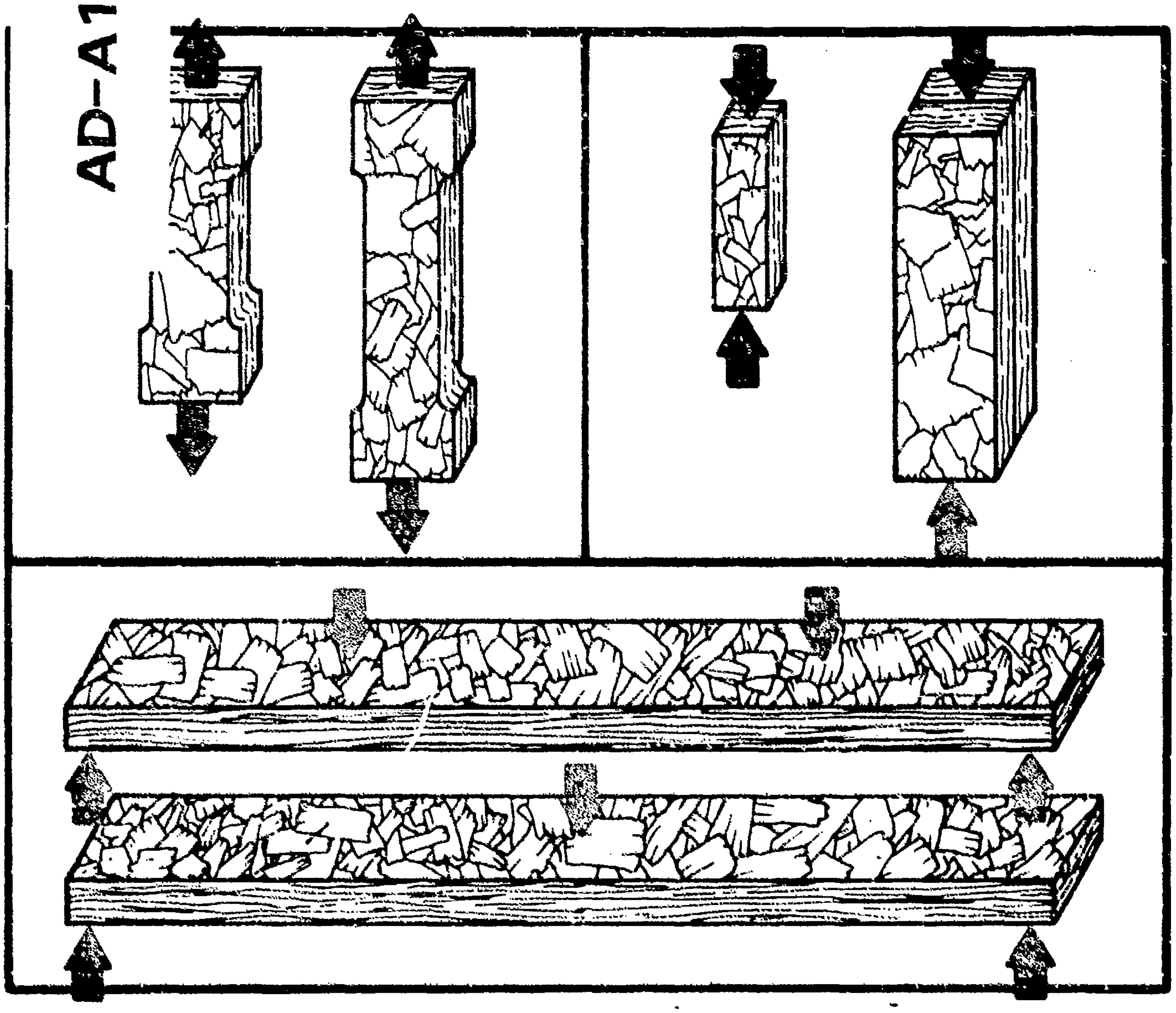
How Some Test Variables Affect Bending, Tension, and Compression Values for Particle Panel Products

J. D. McNatt
M. J. Superfesky



Abstract

Three different particle panel products--particleboard, waferboard, and alined flakeboard (lab-made)--were tested in bending, tension, and compression to evaluate the effects of various test conditions and specimen sizes on strength and stiffness. Standard ASTM-size bending specimens were loaded at midspan or at the quarter points. There were no substantial differences between the two loading methods in average modulus of rupture or modulus of elasticity (MOE) values obtained for any of the three products. Doubling the length and width of the standard compression parallel-to-surface specimen and laminating two thicknesses together resulted in increased compressive strength and MOE values. Increasing the length of the necked-down portion of the standard tension parallel-to-surface specimen from 2 to 6 inches and using a 6-inch rather than a 2-inch gage length did not affect MOE values but did give somewhat lower tensile strength values.

Keywords: Particleboard, flakeboard, waferboard, test methods, bending, tension, compression, shear.

Preface

The research reported here is designed to help develop valid test methods for structural wood particle panels now being introduced into the wood construction market.

Test methods for other materials have been discussed in previous papers written by Forest Products Laboratory (FPL) scientists:

Clauser, W. W. Determining the compressive strength parallel to surface of wood composition boards. Materials Research and Standards 2(12): 996-999; 1962.

Lewis, W. C. Effects of the variables of span, width, and speed of loading on the properties of hardboard. FPL Rep. TM-88; 1953.

Lewis, W. C. Effect of size and shape of specimen on the tensile strength of fiberboards. FPL Rep. 1716; 1948.

Youngquist, W. G.; Munthe, B. P. The effect of a change in testing speed and span on the flexural strength of insulating and structural fiberboards and a proposed new method of test. FPL Rep. 1717; 1956.

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How Some Test Variables Affect Bending, Tension, and Compression Values for Particle Panel Products

J. D. McNatt, Research Forest Products Technologist
M. J. Superfesky,[1] Engineer

Forest Products Laboratory, Madison, Wis.

Introduction

Purpose

The objectives of this study were as follows:
1. To compare bending modulus of rupture (MOR) and modulus of elasticity (MOE) determined from midspan- or quarter-point-loaded particle panel specimens supported on fixed or movable supports with deflection measured by a gage either attached to a yoke hanging on the specimen neutral axis or simply bearing against the underside of the specimen at midspan.
2. To determine the effects of increasing specimen size on tension and compression parallel-to-surface properties.

Background

A number of current standard test methods for evaluating properties of wood-base fiber and particle panel materials (ASTM 1978) were established prior to the introduction of some of the newer particle panel types (ASTM 1949). These methods are satisfactory for products manufactured from small-size wood fibers and particles but may not be suitable for panels made with larger wood elements such as flakes, wafers, and strands. For example, a single large flake may occupy the entire gage length and width of a tension specimen. This could cause erroneous results and considerable variability because the properties of the flake might predominate, rather than the overall properties of the specimen.

Bending tests are presently performed using midspan loading. That is, 3-inch-wide specimens are loaded at the center of a span length 24 times the panel thickness. This method may facilitate testing and simulate some in-service load conditions, but it encourages the specimen to fail at the point of loading. Midspan loading does not permit determination of the true bending modulus because shear deflections comprise a larger percentage of total deflection than in other loading modes. This is discussed further under the section on effects of shear deflection on MOE.

Fixed supports and loading blocks are usually used in bending tests, but perhaps movable supports should be specified to provide a support condition that will also accommodate specimen irregularities such as warping and twisting caused by some exposure conditions prior to testing. In addition, the true deflection of a bending specimen is not measured unless a yoke is attached during loading. The yokeless, fixed-support method recommended in ASTM D 1037-78 may penalize the material tested by overestimating specimen deflection relative to supports and thus underestimating the true MOE.

All of these factors could significantly affect true test results.

[1] Now engineer, U.S. Department of Interior, Office of Surface Mining, Morgantown, W. Va.

Previous Work

Lewis evaluated the effects of specimen size and shape on fiberboard tensile strength (1948) and the effects of span, width, and loading speed on the bending properties of hardboard (1953). Lewis reported "though there was apparently a trend for test results of hardboard to be more variable as widths decreased, it was not enough for any width of specimen to give more reliable average values than any other." Lewis recommended that a 2-inch width be adopted for fiberboard tension specimens to match the standard 2-inch grip size. Several of his recommendations were incorporated into ASTM D 1037. Note that these testing procedures were recommended prior to the advent of flake-type particleboard and are designed for fiberboard and hardboard which do not possess the degree of inhomogeneity on the test specimen size scale that flake-type particleboards do.

Clouser (1962) investigated three alternative specimen types for determining the compression parallel-to-surface properties of fiberboard, hardboard, and particleboard. Different procedures were used to prevent buckling during loading:

1. Lateral support provided for single-thickness specimen.
2. Several layers laminated together to obtain nominal 1-inch thickness.
3. Specimen height limited to no more than four times panel thickness.

These three methods are now included in ASTM D 1037 as standard procedures. Methods 2 and 3 gave essentially the same compressive strength for a 3/8-inch-thick particleboard. Method 1 gave a slightly higher strength value. Method 1 gave an MOE value which was about 10 percent greater than Method 2. No measure of MOE could be obtained by Method 3.

Zhestovskii (1979) compared tensile strength values from both rectangular and "necked-down" specimens of particleboard and concluded that necking down the center portion of the specimen did not decrease the variability of the results. In fact, a rectangular (50- by 250-mm) specimen gave the same strength value and variability as a 50- by 250-mm specimen with the middle 110 mm necked down to 40 mm.

The effect of shear deflections on the total deflection of beams was reported by Newlin and Trayer (1924). The 24:1 span:depth ratio recommended by ASTM D 1037-78 is based on their research. Other research concerning test methods for insulating and structural fiberboards was reported by Youngquist and Munthe (1956).

Research Material

Three different particle panel types were selected as test material:

1. 1/2-inch commercial urea-bonded southern pine particleboard floor underlayment.
2. 1/2-inch commercial phenolic-bonded aspen waferboard.
3. 1/2-inch laboratory-made, phenolic-bonded, 3-layer Douglas-fir flakeboard; random core of ring-cut flakes, alined face layers of disc-cut flakes.

The two commercial products were purchased in 4- by 8-foot sheets (7 of each) from a local supplier. The flakeboard was fabricated as 22- by 26-inch panels at the Forest Products Laboratory (FPL). One-half (4- by 4-ft panel) of each sheet of commercial panel was used in this study. The seven 4- by 4-foot panels were first cut into 2- by 2-foot squares. From each of these squares, four bending specimens, two standard tension specimens, two modified tension specimens, two standard compression specimens, two modified compression specimens, and one interlaminar shear specimen were cut as shown in figure 1. The cutting diagram was similar for the 28 alined flakeboards made at FPL. In all cases, specimen length was parallel to face flake alinement for the laboratory flakeboards.

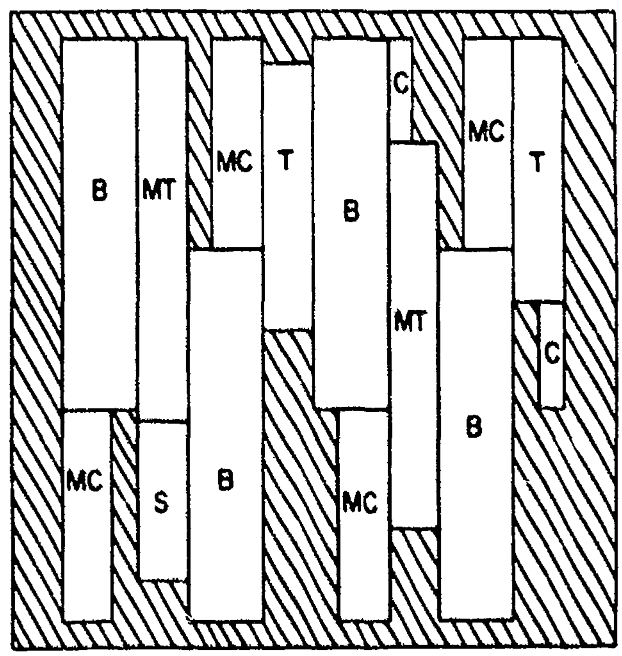

Figure 1.--Cutting diagram for specimens from 2- by 2-foot squares.

Test	Code	No. cut	Specimen size (in.)
Static bending	B	4	3 x 14
Standard tension	T *	2	2 x 10 (necked)
Modified tension	MT	2	2 x 14-1/2 (necked)
Standard compression	C	2	1 x 4
Modified compression	MC	4	2 x 8 (laminated)
Interlaminar shear	S	1	2 x 6

(ML845134)

Research Methods

After all specimens were cut, they were conditioned to equilibrium moisture content at 75 °F and 64 percent relative humidity prior to testing. All tests were conducted according to ASTM D 1037-78 except for the modifications listed below.

Static Bending

Static bending tests were conducted using the four different loading and support conditions listed in table 1. Test conditions Q/F (quarter-point loading with fixed supports) and C/M (midspan loading with movable supports) are illustrated in figures 2 and 3, respectively. Test conditions Q/M and C/F were obtained by interchanging the loading and support systems shown.

Twenty-five bending specimens from each of the three panel types were randomly selected for measuring MOE only. These specimens were not loaded to failure. Each group of 25 was tested using each of the 4 test conditions. This yielded a total of 300 individual MOE values. The testing sequence was also randomized for each group of tests.

During the MOE tests, deflections were measured simultaneously with a yoke attached to the neutral axis of the specimen and a center stand fixed to the test machine. All MOE tests were terminated at a stress level less than the proportional limit of the material.

After MOE tests were completed, 80 additional specimens from each different material were randomly selected and tested to failure in static bending using each of the four test conditions described in table 1. This should have resulted in 20 tests per material per test condition. Due to errors in assigning specimens to the various groups, however, the actual number of specimens in each group was as indicated below:

	Midspan loading		Quarter-point loading		
Material	Fixed reactions	Movable reactions	Fixed reactions	Movable reactions	Total
	Number of specimens tested				
Alined flakeboard	19	28	14	19	80
Waferboard	26	24	16	14	80
Particleboard	20	23	20	17	80

Both MOR and MOE were calculated for each of the 80 specimens from each of the three panel types.

Table 1.--Description of flexure tests

Test condition[1]	Support condition[2]	Loading[3]	Deflection measurement[4]
C/F	Fixed	Midspan	Yoke and stand
Q/F	Fixed	1/4-point	Yoke and stand
C/M	Movable	Midspan	Yoke and stand
Q/M	Movable	1/4-point	Yoke and stand

[1]The same 25 specimens from each panel type were used for each test condition for stiffness tests.

[2]Fixed support condition means the standard support described by ASTM D 1037-78. Movable means that the supports and load points can rotate (fig. 2).

[3]1/4-point loading means load points are equidistant between center span and each support (fig. 3).

[4]Yoke and stand were used simultaneously to measure all deflections. The span for all bending tests was 12 in.

Tension Parallel to Surface

Forty standard 2- by 10-inch tension specimens having a 2-inch-long reduced width and 40 modified 2- by 14-1/2-inch tension specimens having a 6-1/2-inch-long reduced width were prepared from each type of material. The modified specimens were identical to the standard (ASTM D 1037) except that the area necked down to a 1-1/2-inch width was approximately 6-1/2 inches long to accommodate a 6-inch gage length (fig. 4). Ultimate load and load-deformation data were obtained for all tension specimens. Gage lengths were 2 inches for the standard specimen and 6 inches for the modified specimen.

Compression Parallel to Surface

Forty standard 1/2- by 1- by 4-inch compression specimens and 40 modified 1- by 2- by 8-inch compression specimens were prepared from each type of material. The larger modified specimens consisted of two pieces of 1/2- by 2- by 8-inch material bonded together with an epoxy adhesive that sets at room temperature (fig. 5). Ultimate load and load-deformation data were obtained for all compression specimens (2-in. gage length for the standard specimens and 6-in. gage length for the modified specimens).

Interlaminar Shear

Twelve standard 2- by 6-inch interlaminar shear specimens were tested from each type of material according to ASTM D 1037-78, Section 128-135. Ultimate load and load-deformation data were recorded for all specimens.

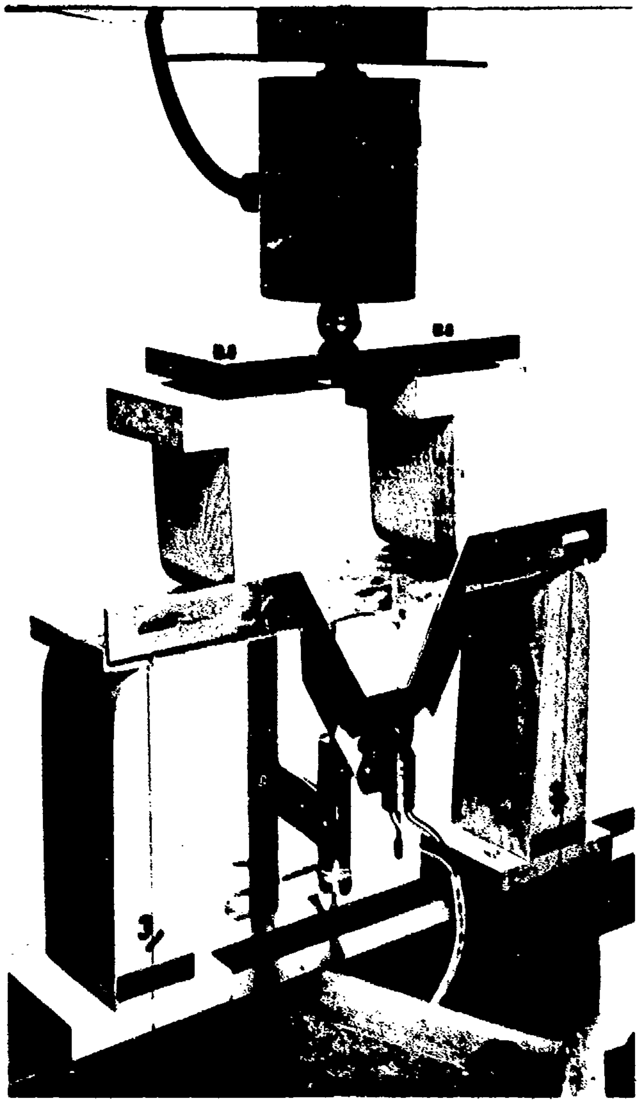

Figure 2.--Quarter-point loading of bending specimens using nonadjustable (fixed) supports. (M143408-3)

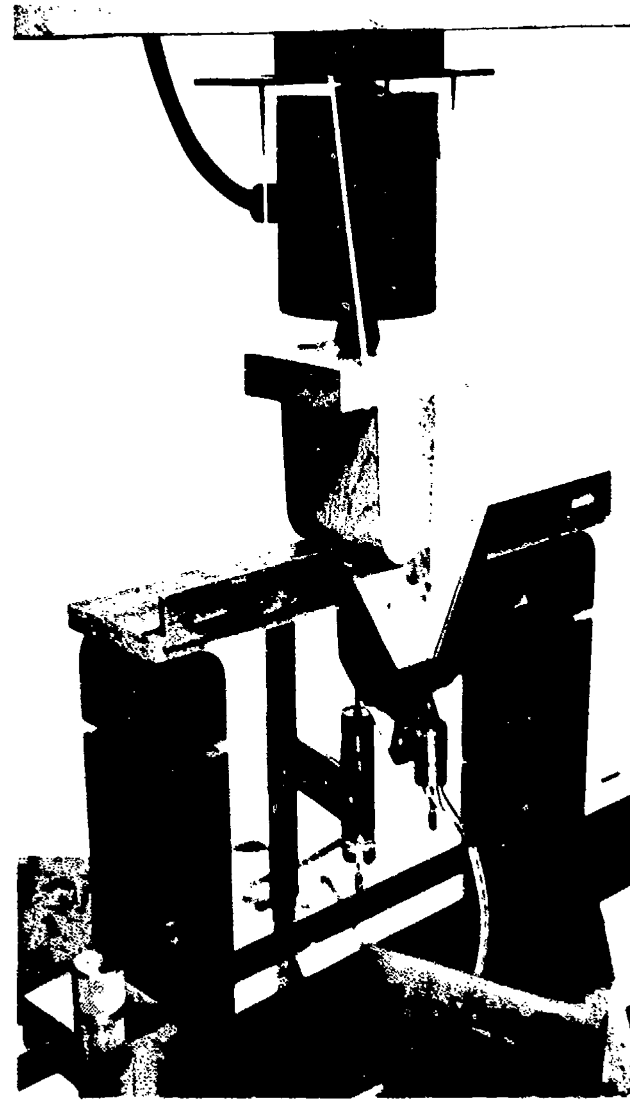

Figure 3.--Midspan loading of bending specimen using adjustable supports. (M143409-5)

Results and Discussion

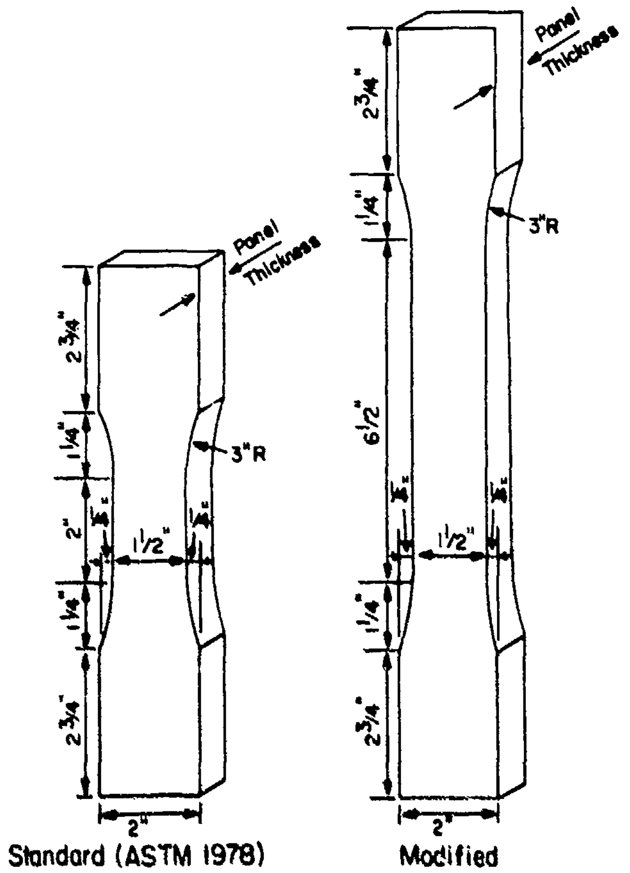

Figure 4.--Standard and modified tension specimens showing differences in length and "necked-down" area. (ML845135)

Static Bending

MOE.--Average MOE values for the 25 specimens from each of the 3 panel types loaded for deflection only are compared in figure 6. Since all the specimens tested in this study were flat (not warped or twisted), there was no reason to expect any difference in properties between those supported by movable or fixed reactions. Generally this was true. With two exceptions, the differences in MOE when specimens were supported on fixed and movable reactions were less than 3 percent for all three panel types. The two exceptions occurred in the alined flakeboard specimens loaded for deflection only (fig. 6). Average MOE determined from the "stand" deflection reading when specimens were loaded at midspan over fixed supports (C/F) was 11 percent below the corresponding value for the same specimens over movable supports (C/M). Also, average MOE from the stand deflection reading when these specimens were loaded at the quarter points over fixed supports (Q/F) was 7 percent below the corresponding MOE for them over movable supports (Q/M). Figure 6 likewise shows that the average MOE determined from the stand deflection reading when the specimens were loaded at midspan over fixed supports (C/F) was 15 percent below the average value determined from the "yoke" deflection readings. Also, the average MOE from the stand deflection reading when the specimens were loaded at the quarter points supported on fixed reactions (Q/F) was 9 percent below the average value determined from the yoke deflection readings.

For the other two modes of loading the alined flakeboard (C/M and Q/M) and for all four modes of loading the waferboard and particleboard, the stand and yoke MOE averages differed very little.

Statistical analysis of the data from the bending specimens loaded only for deflection indicated that there were significant differences between a number of the four modes of loading even though the mean MOE values differed by only a few percent (table 2). For example, MOE values determined from the stand deflection readings were found to be significantly different in the statistical analysis for midspan and quarter-point loading even though they were all within 5 percent of each other (table 2, line 6). It would seem that for practical purposes, differences of this magnitude could be considered unimportant.

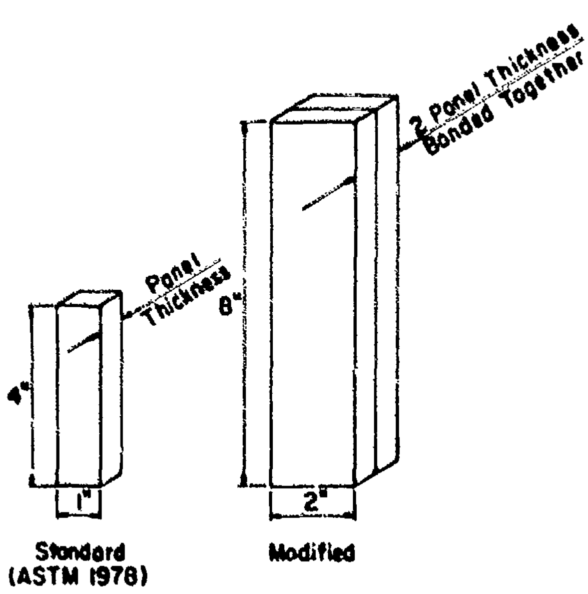

Figure 5.--Standard and modified compression specimens. (ML845136)

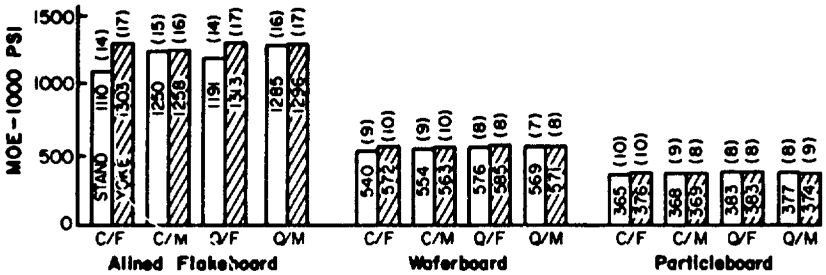

Figure 6.--Comparison of modulus of elasticity (MOE) values calculated from stand and yoke deflection readings; C = midspan loading, Q = quarter-point loading, F = fixed supports, M = movable supports (from specimens loaded for deflection only). Each value is the average of 25 specimens. Coefficients of variation are given in parentheses. (ML845137)

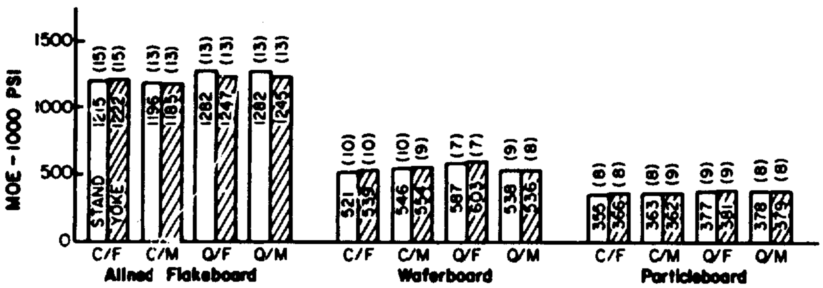

Figure 7.--Comparison of modulus of elasticity (MOE) values calculated from stand and yoke deflection readings; C = midspan loading, Q = quarter-point loading, F = fixed supports, M = movable supports (from specimens loaded to failure). Coefficients of variation are given in parentheses. (ML845138)

Table 2.--Statistical analysis of MOE data from bending specimens loaded for deflection only. C = midspan loading, Q = quarter-point loading, F = fixed supports, M = movable supports. Loading methods underlined by the same line are not significantly different as determined by Duncan's multiple range test (Ott 1977).

Variable	Material	Multiple comparisons, high to low			
Yoke MOE	Alined flakeboard	Q/F	C/F	Q/M	C/M
	Waferboard	Q/F	C/F	Q/M	C/M
	Particleboard	Q/F	C/F	Q/M	C/M
		Q/F	C/F	Q/M	C/M
Stand MOE	Alined flakeboard	Q/M	C/M	Q/F	C/F
	Waferboard	Q/F	Q/M	C/M	C/F
	Particleboard	Q/F	Q/M	C/M	C/F
Yoke MOE	Alined flakeboard	C/F	Q/F	Q/M	C/M
Stand MOE	Waferboard	C/F	C/M	Q/F	Q/M
	Particleboard	C/F	C/M	Q/F	Q/M

Average MOE values for the bending specimens loaded to failure are shown in figure 7. The differences between the stand and yoke MOE values for the C/F and Q/F flakeboard specimens loaded only for deflection did not show up in the specimens loaded to failure. Otherwise the MOE data for specimens of all three panel types loaded to failure were essentially the same as those for specimens loaded only for deflection. For this reason it is felt that the above differences were not real, but were due to experimental error. Errors in assigning the correct number of specimens to each group in this series of tests (as discussed earlier under Research Methods) precludes making any accurate tests of statistically significant differences among average MOE values. Overall, it appears reasonable to conclude that conditions of loading (C/F, C/M, Q/F, Q/M) and method of measuring deflection (stand, yoke) did not substantially affect MOE values of the three panel types tested. Also, coefficients of variation shown in figures 6 and 7 indicate that variability of test results was not affected.

Effect of interlaminar shear deflection on MOE.--Since the two methods used to record deflection (stand and yoke) measured maximum deflection over the 12-inch span for both midspan and quarter-point loading, the effect of shear deflection could not be determined directly. Instead indirect determinations were made using the shear modulus values from the interlaminar shear tests and the E/G ratios as discussed below. Average interlaminar shear properties for the three panel types and the corresponding E/G ratios are:

Panel type	Shear strength	Shear modulus	E/G
	Lb/in.²	*Lb/in.²*	
Alined flakeboard	455	53,200	23.5
Waferboard	300	30,600	18.5
Particleboard	305	43,200	8.5

Corrections for shear deflection were made using the equations:

For Midspan Loading (Seely and Smith 1961)

$$E = \frac{P'L^3}{48\Delta I} 1 + \frac{1}{K}\ E/G \cdot h^2/L^2 \qquad (1)$$

For Quarter-Point Loading (ASTM 1976)

$$E = \frac{P'a}{48\Delta I}\ \frac{3L^2 - 4a^2}{1 - \frac{3P'a}{5bhG\Delta}} \qquad (2)$$

where

a = 1/2 shear span for two-point loading (L/4 for quarter-point loading)
b = Width of bending specimen
E = MOE in bending
G = Interlaminar shear modulus
h = Specimen thickness
I = Moment of inertia of the specimen
K Shear coefficient, ratio of average shear strain on a section to shear strain at the centroid (Cowper 1966)
L = Span of bending specimen
P' = Total load on specimen at proportional limit
Δ = Midspan deflection at load P'

For a rectangular member in bending

$$K = \frac{10(1 + \nu)}{12 + 11\nu} \qquad (3)$$

where ν is the Poisson's ratio for the material. Strictly speaking this applies only to isotropic materials, so it is used here as an approximation.

K is independent of the width/depth ratio (Cowper 1966). Only one source of measured values for Poisson's ratio was found. Chen and Tang (1982) reported an average value of approximately 0.25 for a 1/2-inch-thick flakeboard. This gives a value of K = 0.85 which was used in equation (1). Even if this Poisson's ratio value is off by 50 percent or more, the effect on the value of K is practically negligible.

Using the E/G ratios and K = 0.85 in equation (1) and the above G values in equation (2), the effect of shear deflection on MOE was determined to be less than 5 percent for all three materials as shown below. Also, the effect was only slightly greater for midspan loading as compared to quarter-point loading. It is obvious that these correction factors increase as the value of E/G increases.

Percent increase in MOE when corrected for deformation due to shear

Material	Midspan loading eq. 1	Quarter-point loading eq. 2
Alined flakeboard	4.9	3.7
Waferboard	3.8	2.9
Particleboard	1.8	1.3

The above percent increase values for midspan loading are essentially the same as values determined from the equation given by Newlin and Trayer (1956):

$$\Delta = \frac{P'L^3}{48EI} + \frac{0.3P'L}{bh\ G} \qquad (4)$$

MOR.--Average MOR values for the bending specimens loaded to failure are shown in figure 8. Quarter point versus midspan did not seem to be a factor in MOR for the waferboard and particleboard specimens or in the variability of the individual test values. However, MOR from the quarter-point-loaded alined flakeboard specimens averaged 10 percent below MOR for midspan-loaded specimens. Coefficients of variation for the quarter-point-loaded alined flakeboard specimens (13 and and 15 pct) were somewhat below those of the midspan-loaded specimens (17 and 19 pct).

Tension Parallel to Surface

MOE.--Average MOE values from the standard tension specimen (2-in. necked-down length) and the modified specimen (6-in. necked-down length) were within 4 percent of each other for all three materials tested (fig. 9). This magnitude of difference was not large enough to be statistically significant. Coefficients of variation of individual test values were greater for the standard specimen: 3 percentage points for the alined flakeboard (16 vs. 13 pct) and the particleboard (14 vs. 11 pct), but 9 percentage points for the waferboard (21 vs. 12 pct).

As mentioned in the Introduction, a single large flake may occupy the entire 2-inch gage length of a standard tension specimen and influence results. Apparently this did not happen in this series of tests.

Tensile strength.—Average tensile strength of the particleboard from the standard and modified specimens differed by only 2 percent (fig. 10). However, average tensile strength from the modified specimen averaged 13 percent less for the alined flakeboard and 10 percent for the waferboard. The differences in strength between the standard and modified specimen were statistically significant for the waferboard and flakeboard, but not for the particleboard. These results are consistent with the makeup of the panels. The smaller pieces of material in the particleboard (planer shavings, sawdust) permit a smaller area to be representative of the strength of the material; therefore no change in test results occurred when the necked-down portion of the specimen was increased from 2 to 6 inches. The larger wood elements and accompanying inhomogeneity of the waferboard and 3-layer flakeboard reduced the probability that the 2-inch length would represent the strength of the material. The results are also consistent with the "weakest link theory" which implies that the strength of a large member loaded in tension would be equal to the strength of the weakest of small pieces cut from the large member (Bohannan 1966).

For the same reason, it would seem that the tensile strength data from the standard-size specimen would also be more variable. However, for all three materials, coefficients of variation for the data from the standard and modified specimens were essentially the same.

Compression Parallel to Surface

MOE.--For all three panel types, average MOE values from the modified (2 by 8 in. laminated) compression specimen were greater than those from the standard (1 by 4 in. single thickness) specimen (fig. 9): 6 percent greater for the alined flakeboard, 20 percent greater for the waferboard, and 15 percent greater for the particleboard. The waferboard and particleboard differences were statistically significant.

Since two thicknesses of material were glued together to form a modified specimen, it is believed that the increase in compressive MOE was due to load sharing. Doubling of the thickness and increasing the size of the specimen increases the probability of including both weaker and stronger pieces of material. However, since two thicknesses were loaded in parallel, it is probable that load sharing occurred; i.e., the weaker, less stiff material deflected and the properties of the stronger, stiffer material predominated (Zahn 1970). For each of the materials, coefficients of variation were less for the modified specimen: 8 percent versus 10 percent for the particleboard, 10 percent versus 22 percent for the waferboard, and 12 percent versus 26 percent for the alined flakeboard.

Compressive strength.--As would be expected from the discussion above, the modified specimen yielded higher strength values than did the standard specimen (fig. 10): 23 percent higher for the alined flakeboard, 15 percent higher for the waferboard, and 21 percent higher for the particleboard. All these differences were statistically significant. Coefficients of variation for the strength data from the modified specimen were somewhat less for both the waferboard (8 vs. 14 pct) and the particleboard (8 vs. 10 pct).

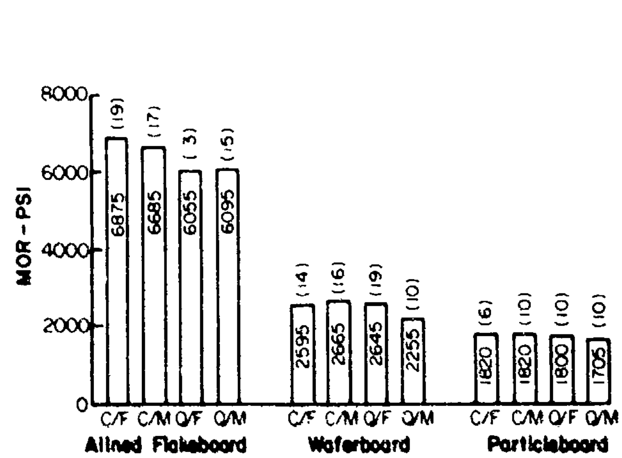

Figure 8.--Comparison of modulus of rupture (MOR) determined from midspan- and quarter-point-loaded bending specimens. (ML845139)

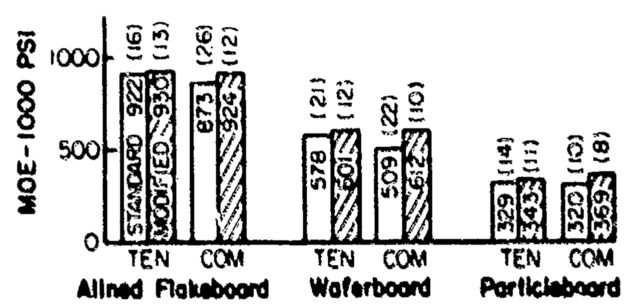

Figure 9.--Comparison of modulus of elasticity (MOE) values determined from standard ASTM specimens and modified specimens for tension (TEN) and compression (COM) parallel-to-surface loading. Values are the averages of 40 specimens. (ML845140)

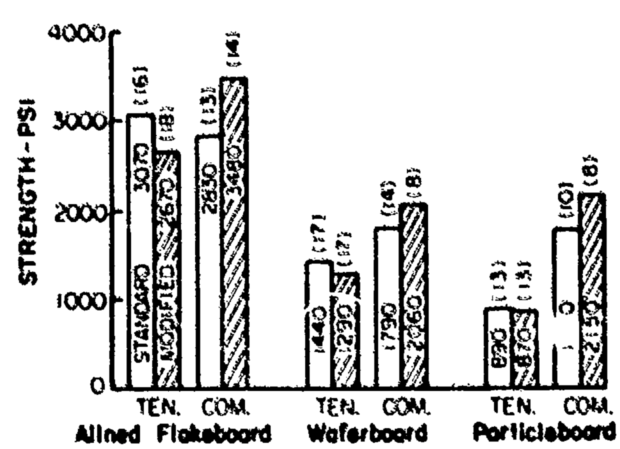

Figure 10.--Comparison of strength values determined from standard ASTM specimens and modified specimens for tension (TEN) and compression (COM) parallel-to-surface loading. Values are averages of 40 specimens. (ML845141)

Conclusions

The following conclusions are drawn from static bending and tension and compression parallel-to-surface tests on a commercial underlayment particleboard, a commercial waferboard, and a laboratory-made 3-layer flakeboard with face flakes only alined (all panels were 1/2 in. thick):

1. Using the standard ASTM-size bending specimen, 1/2 by 3 by 14 inches, tested on a 12-inch span, quarter-point loading gave essentially the same average MOE and MOR values as midspan loading for all three panel types. Because the span:depth ratio was 24:1, the effect of shear deformation on MOE was small (1.3-4.9 pct). Use of movable reactions to accommodate warping of specimens had no bearing on results since all specimens were essentially flat.
2. Increasing the necked-down area in the tension parallel-to-surface specimen from 2 to 6 inches did not affect MOE values, but did decrease tensile strength values, especially for the two products made from larger wood elements (waferboard and flakeboard).
3. Doubling the dimensions of the compression parallel-to-surface specimen from 1/2 by 1 by 4 inches to 1 by 2 by 8 inches resulted in higher strength and stiffness values. The most likely cause was load sharing since the larger specimen consisted of two thicknesses of the panel laminated together, and the properties of the stronger, stiffer material dominated.

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